UNIVERSITY OF CAMBRIDGE

High performance Carnot Batteries based on hybrid cycles

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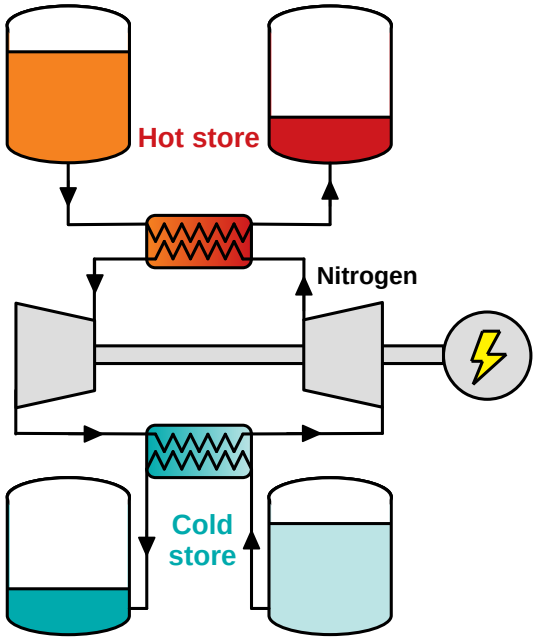
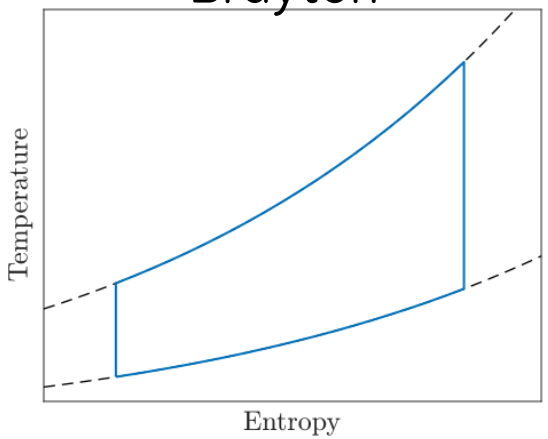
IWCB 2020

Carnot Battery cycles



Brayton



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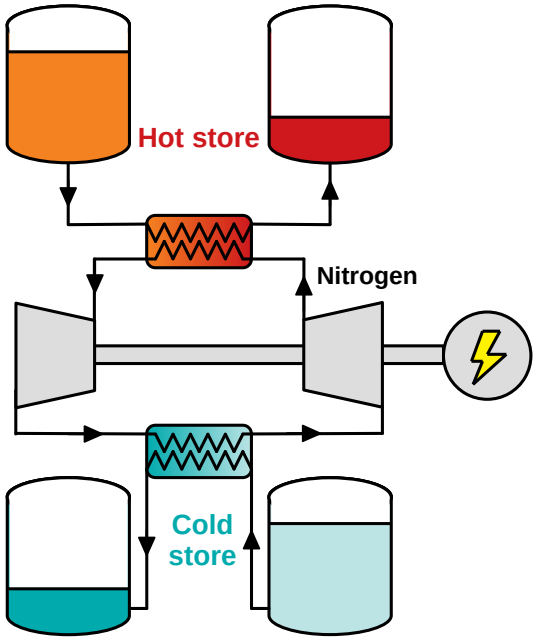

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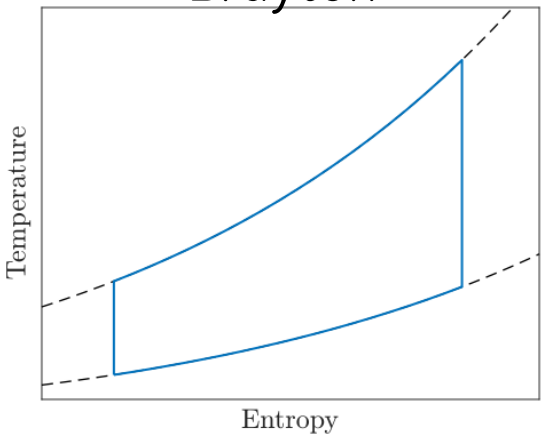
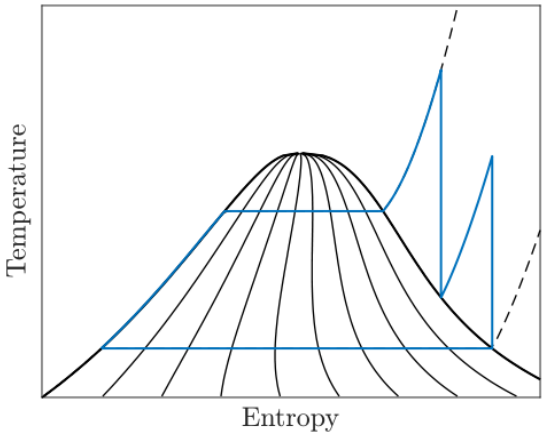


Rankine



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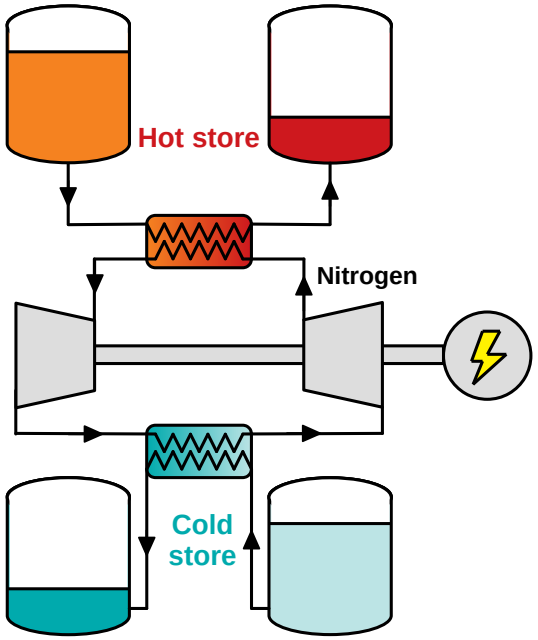

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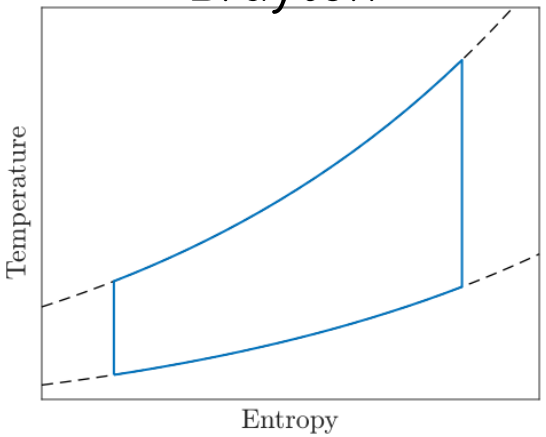

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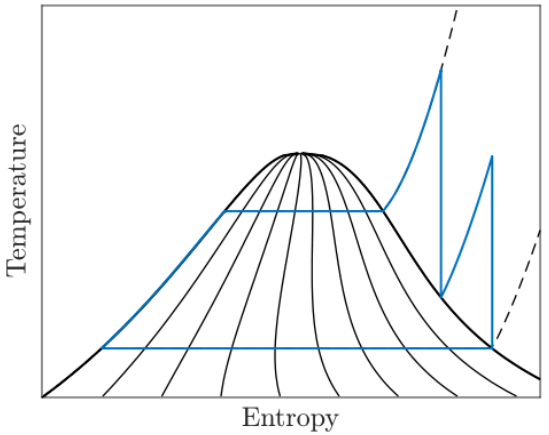

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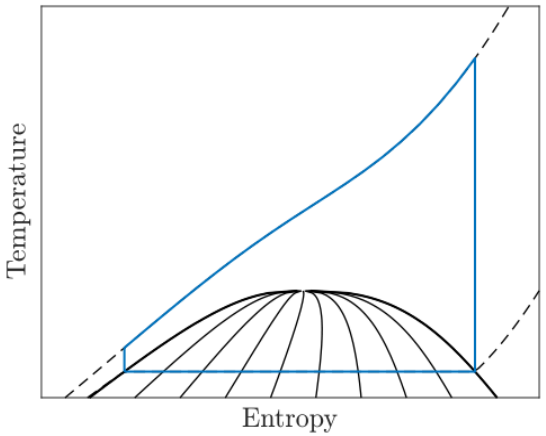

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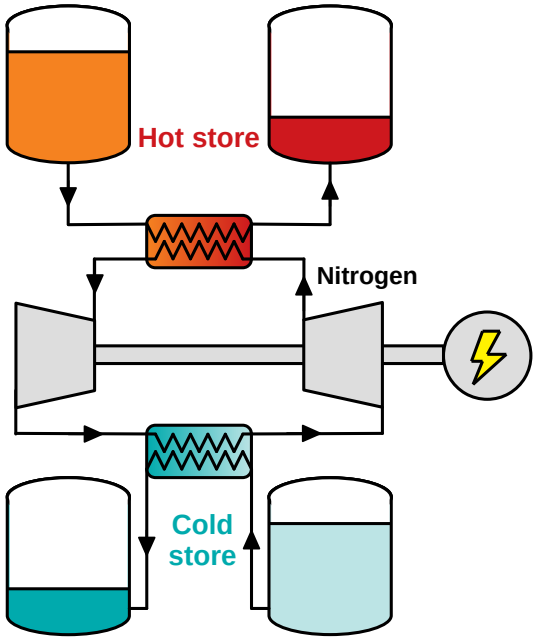

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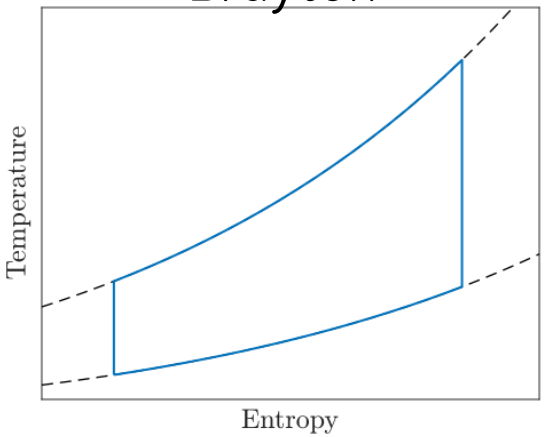

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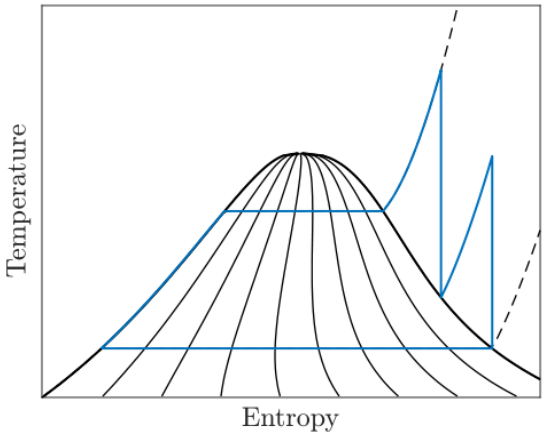

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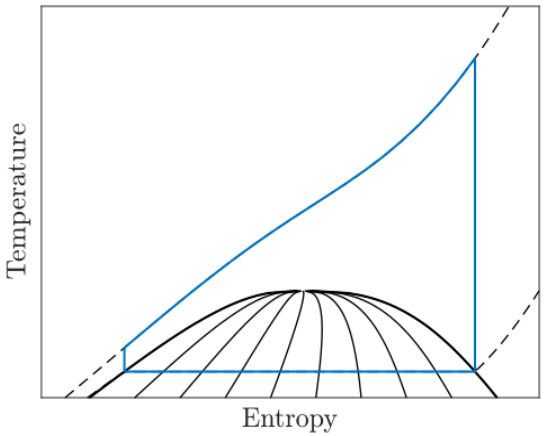
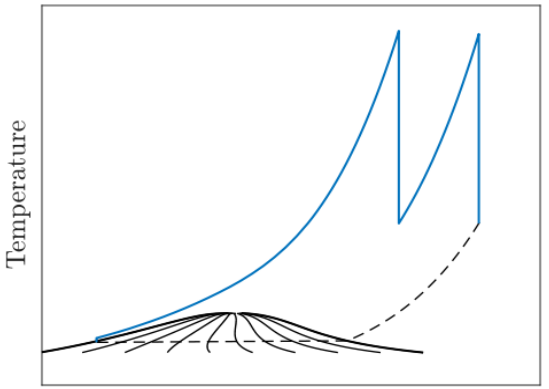


Liquid air



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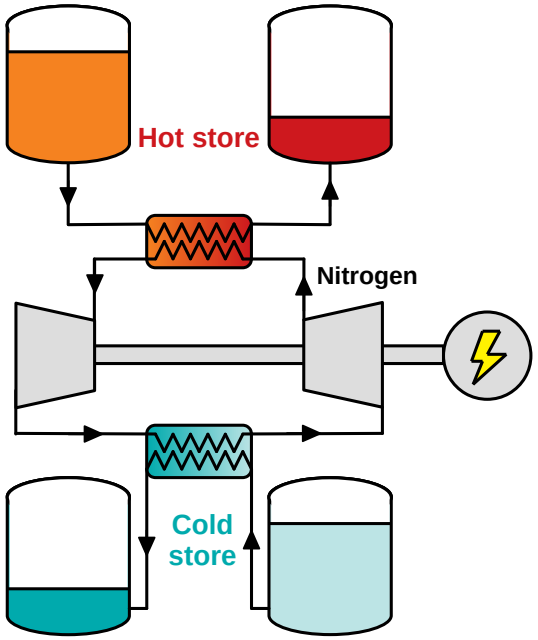

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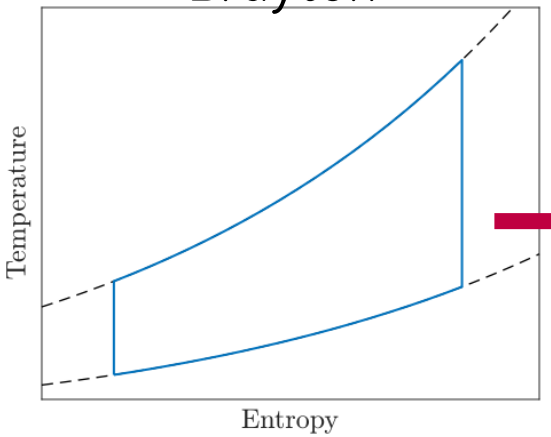

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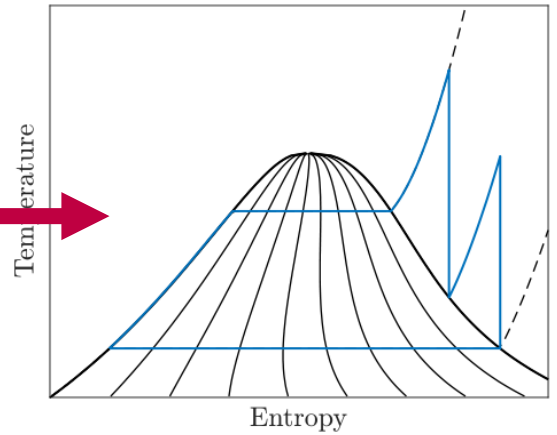

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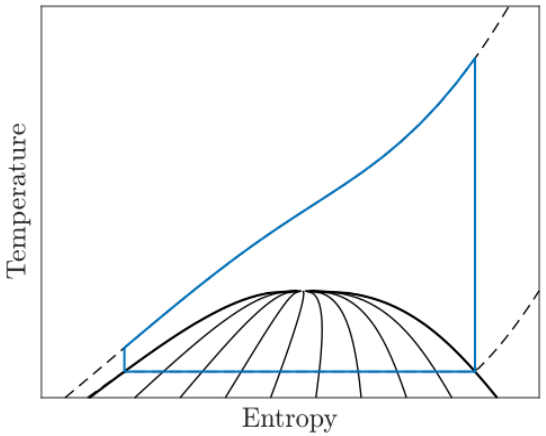

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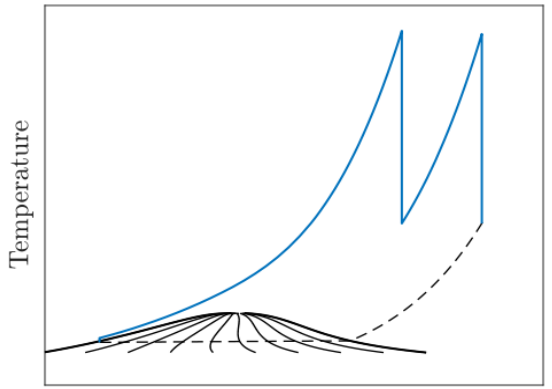
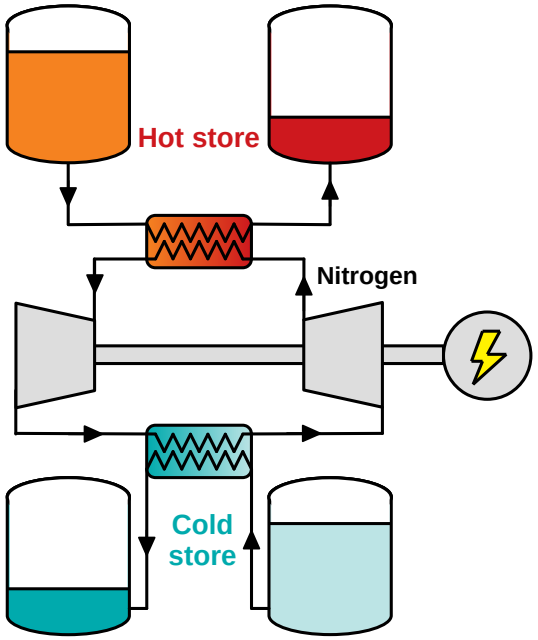
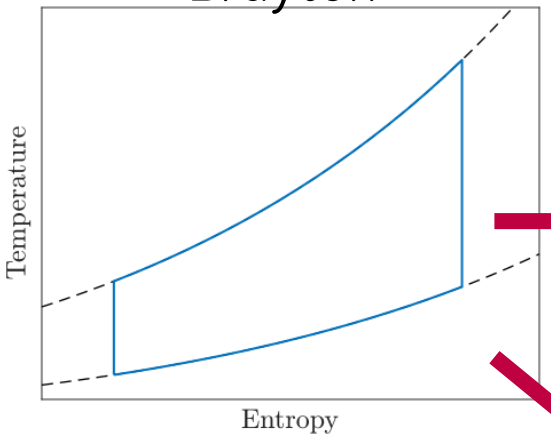


Brayton + Rankine
= energy storage
+ power plant

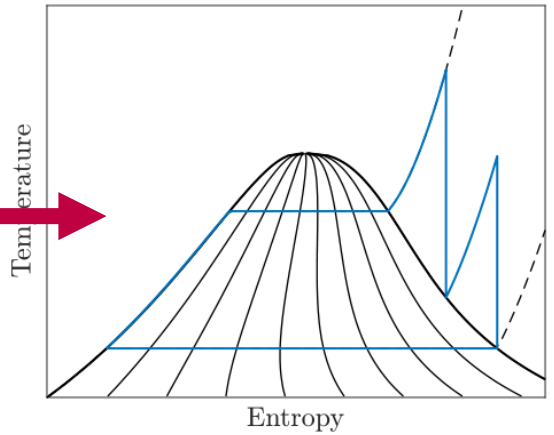
Carnot Battery cycles



Brayton



Rankine



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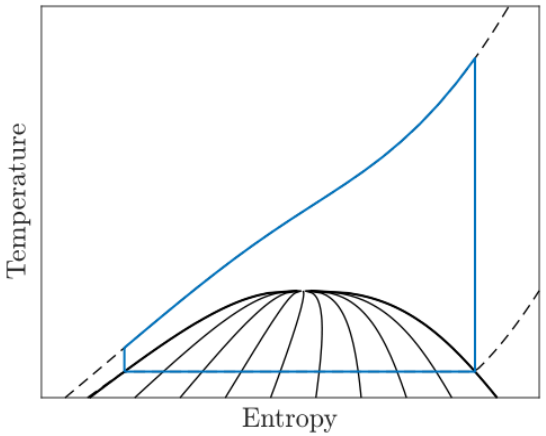
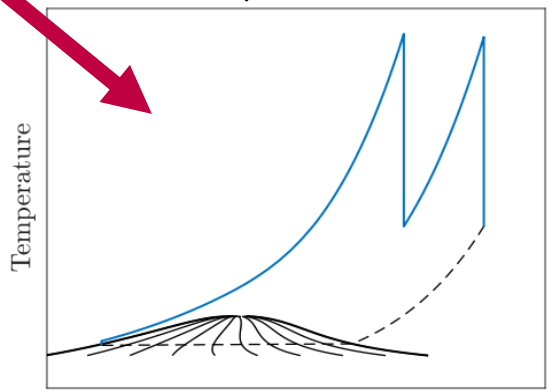
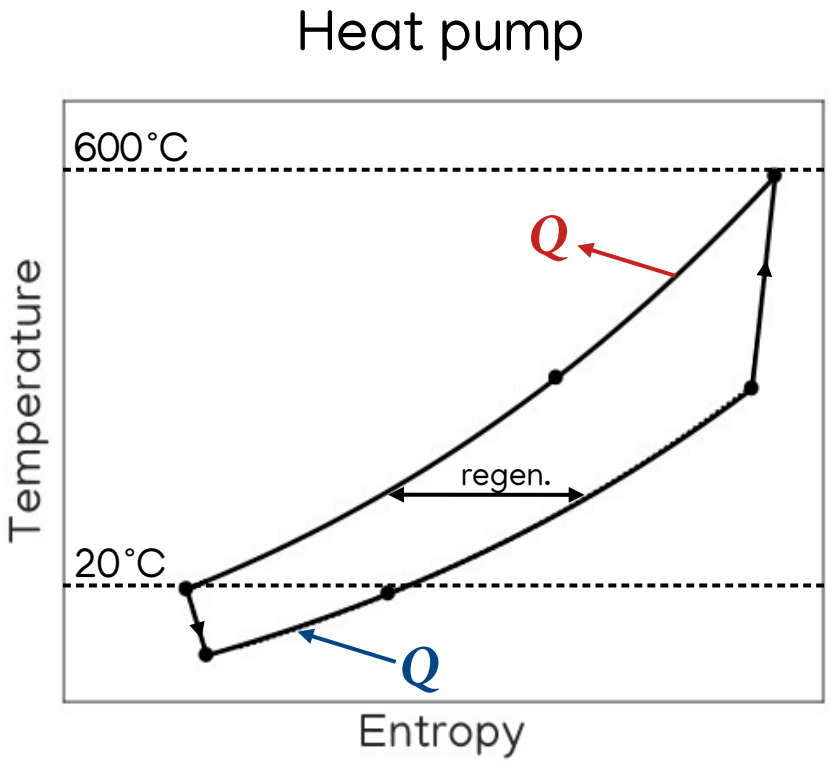


Liquid air



Brayton + Liquid air
= High performance

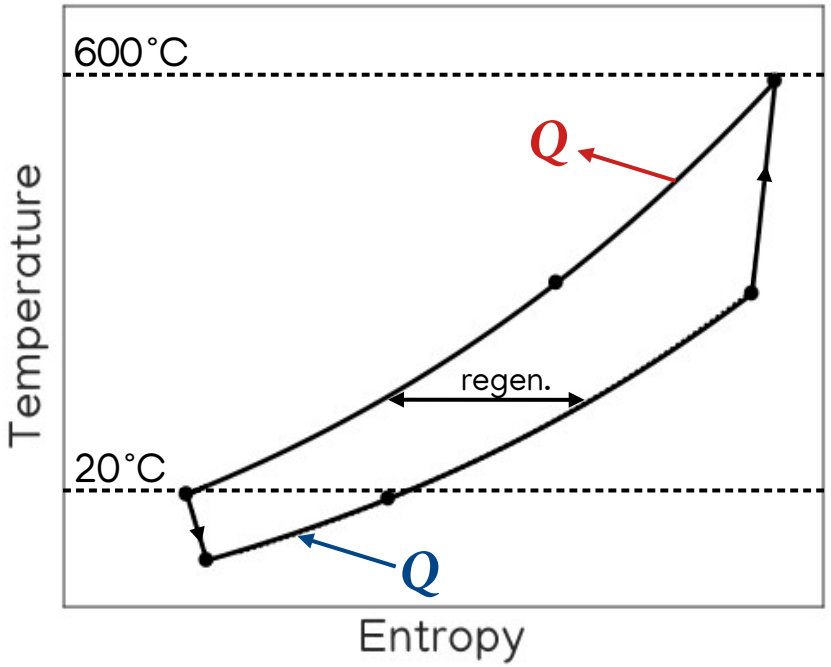
Brayton heat pump



- High temperature heat
- Useful to drive heat engines

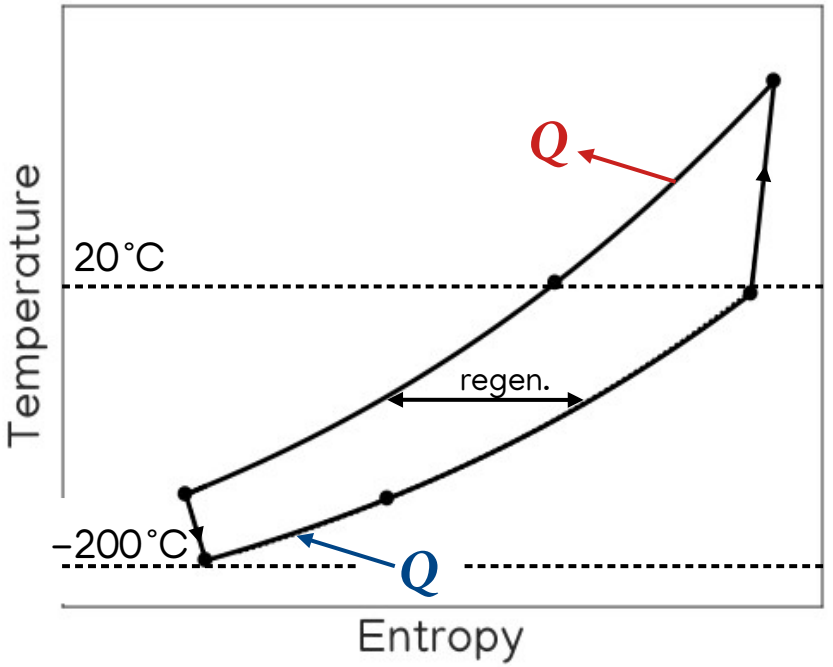
Brayton heat pump

Heat pump



- High temperature heat
- Useful to drive heat engines

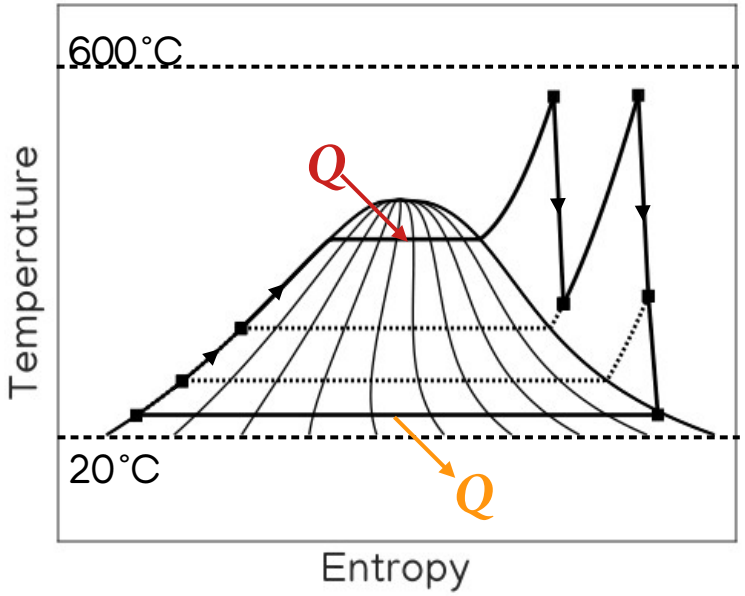
Refrigerator



- Cryogenic cold
- Useful to drive liquefier

Rankine

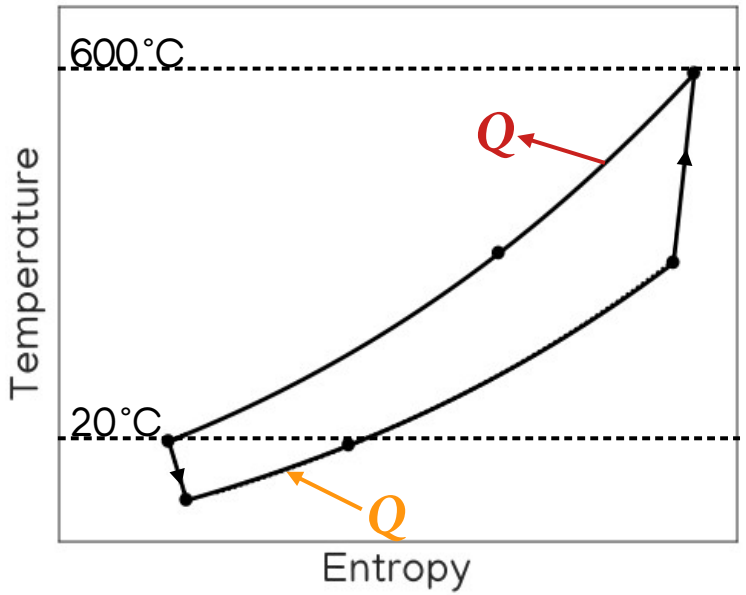
Heat engine



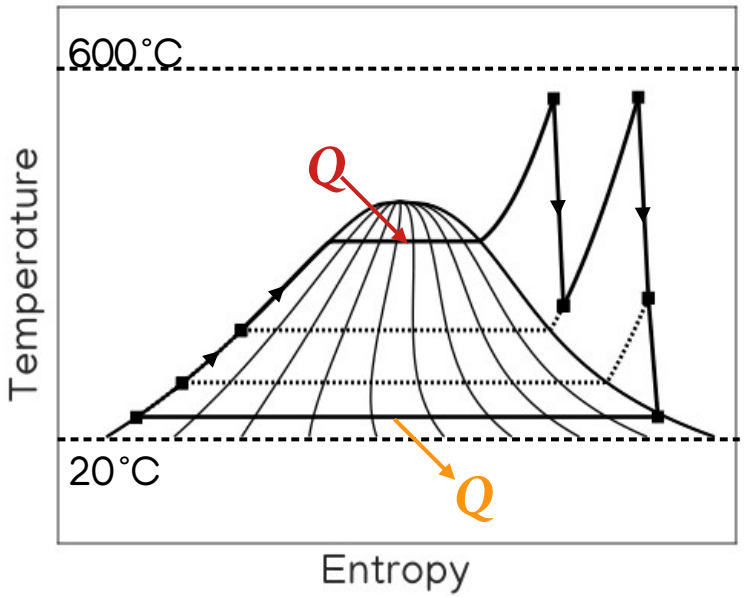
- Thermal efficiency ≈40%
- Exergetic efficiency ≈85%
- Hard to run as heat pump

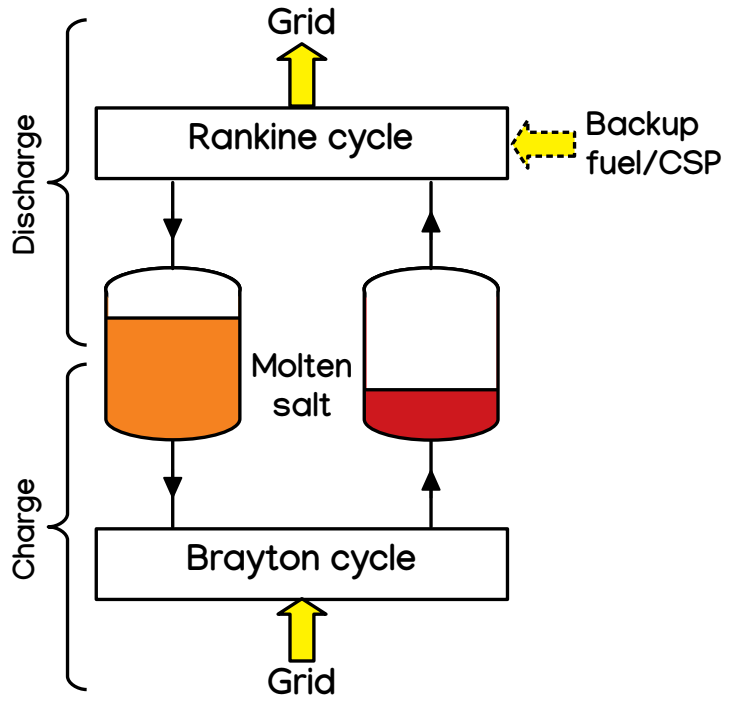
Brayton–Rankine

Heat pump



Heat engine

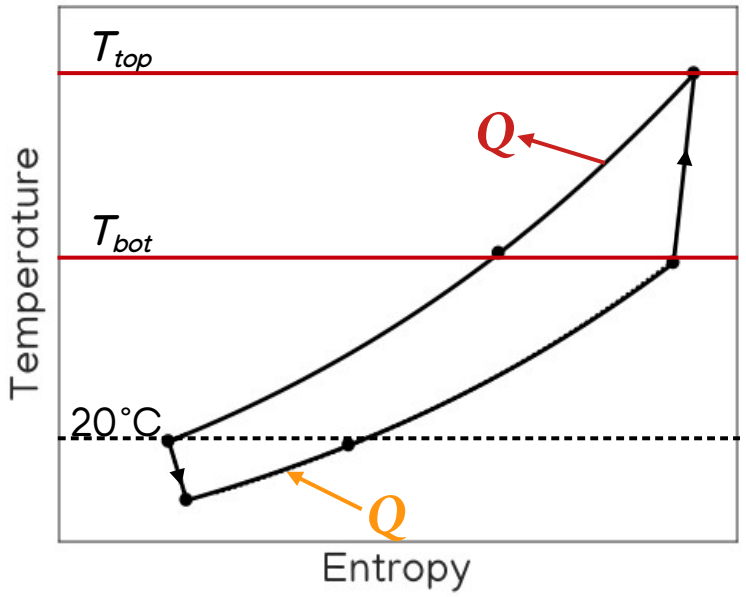




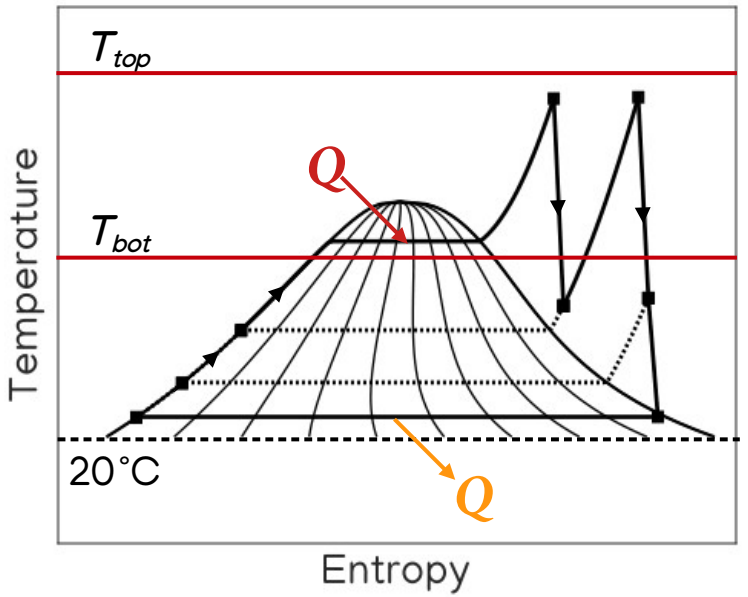
- Can retrofit numerous power plants
- Energy storage + backup power generation!

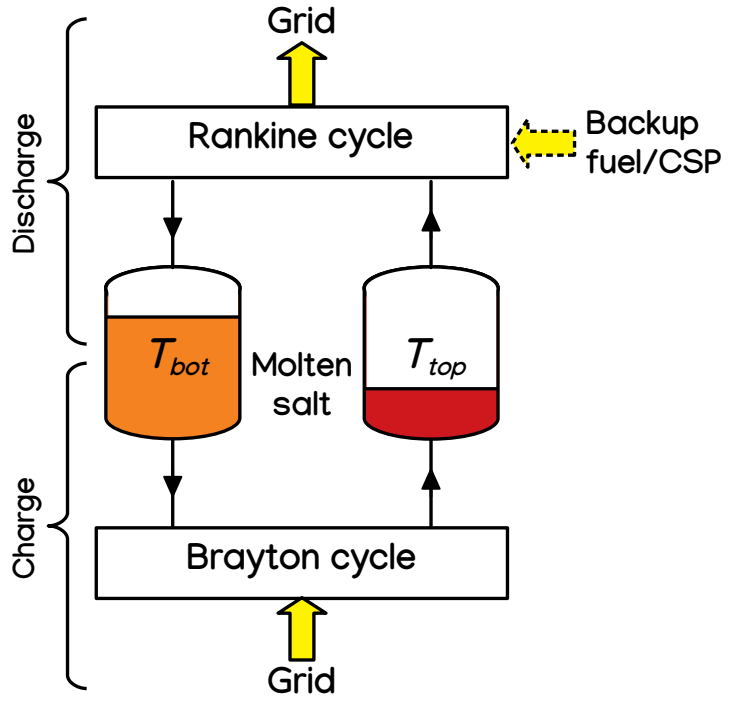
Brayton–Rankine

Heat pump



Heat engine





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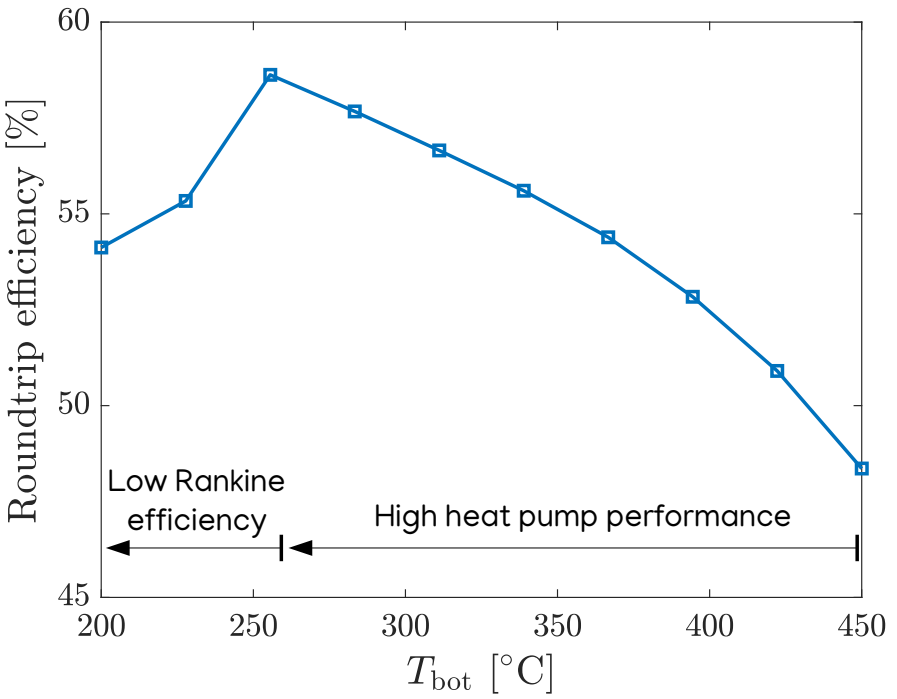
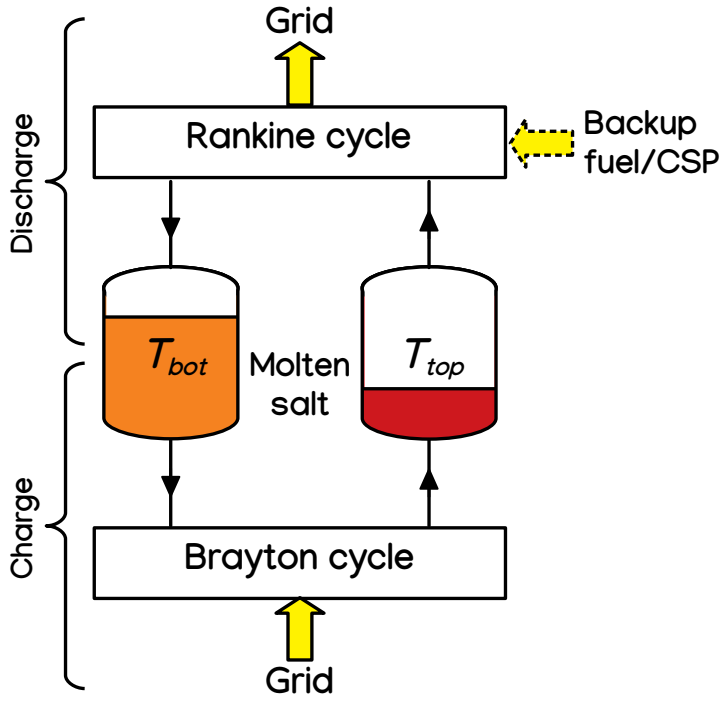
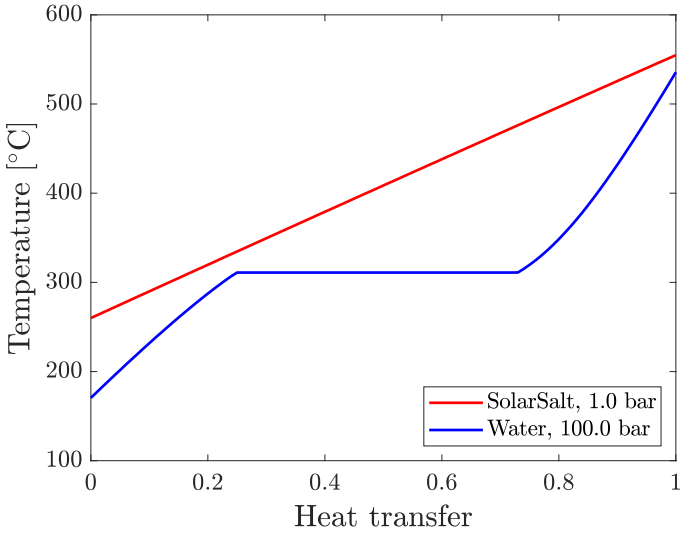
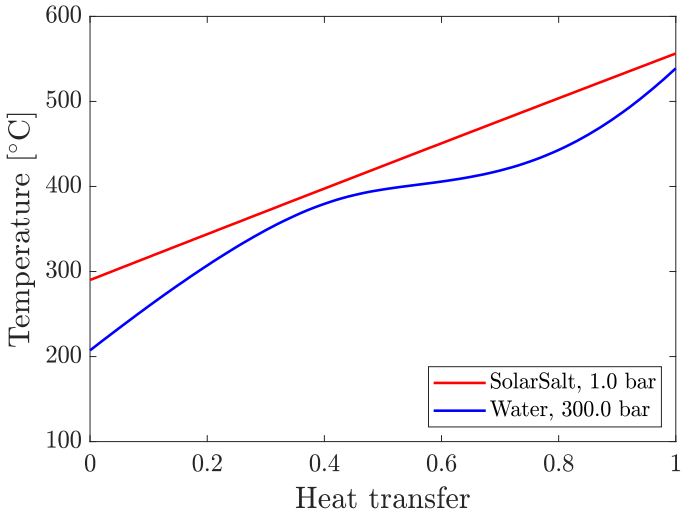
Brayton–Rankine

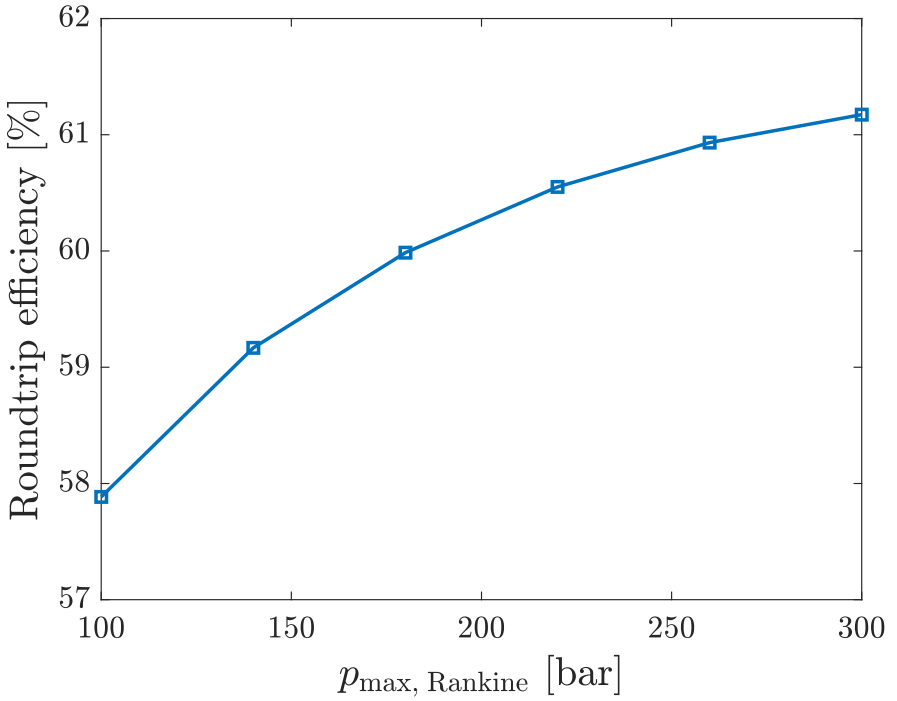


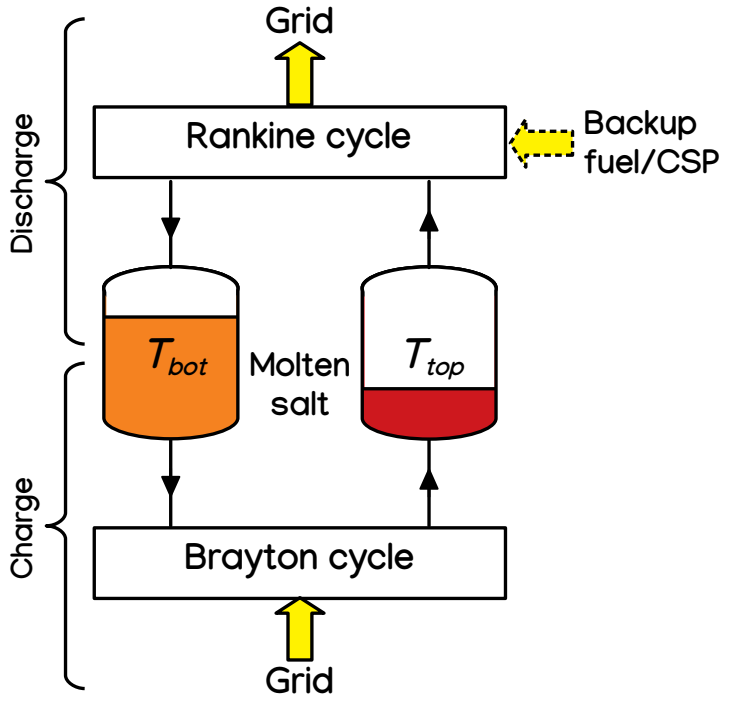


Brayton–Rankine





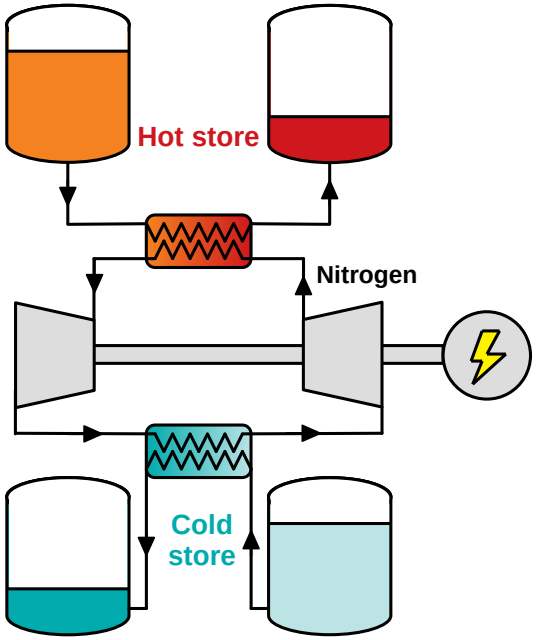




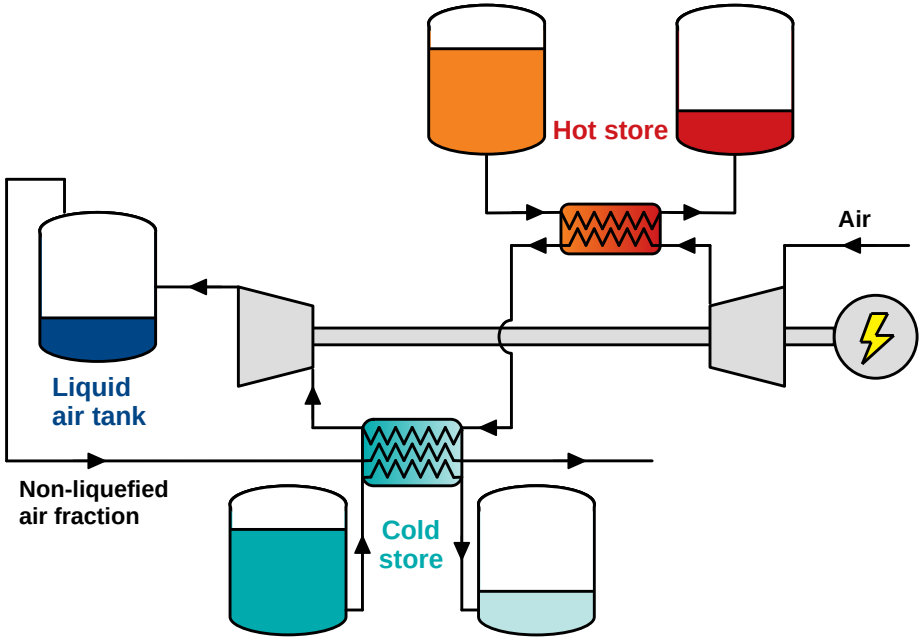
Brayton–Liquid air

Brayton–Liquid air

Brayton cycle

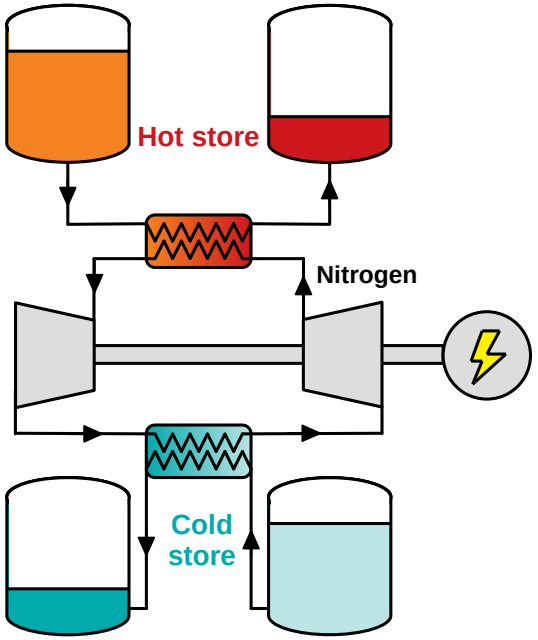


Liquid air cycle



Brayton–Liquid air

Brayton cycle



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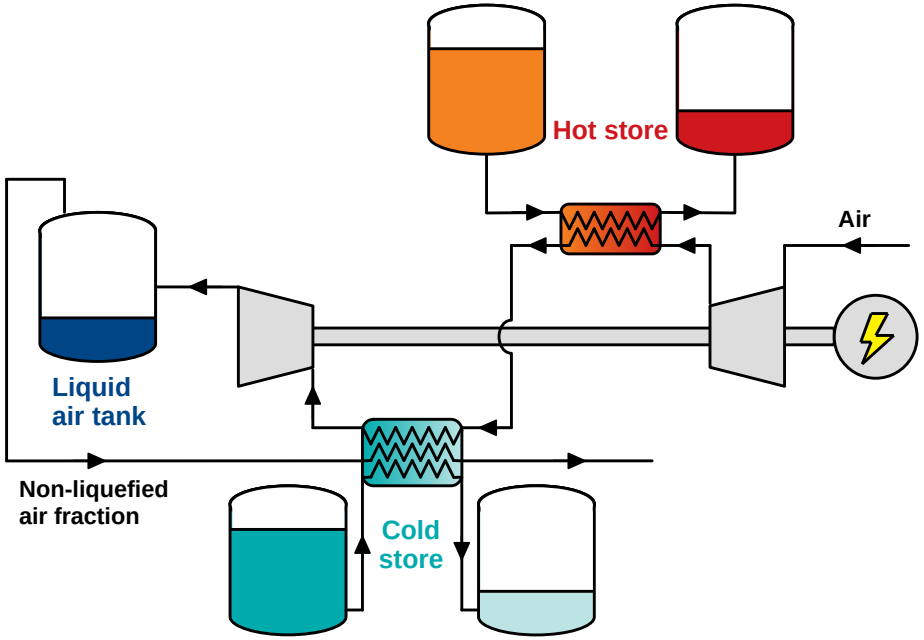
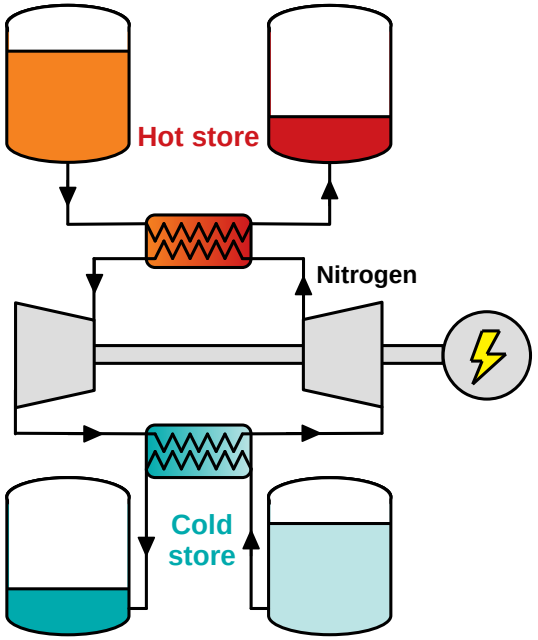


Highview Power

- 2018: Comissioned first pilot plant; 5 MW / 15 MWh
- 2020: Starts construction of new plant; 50 MW / 250 MWh

Brayton–Liquid air

Brayton cycle



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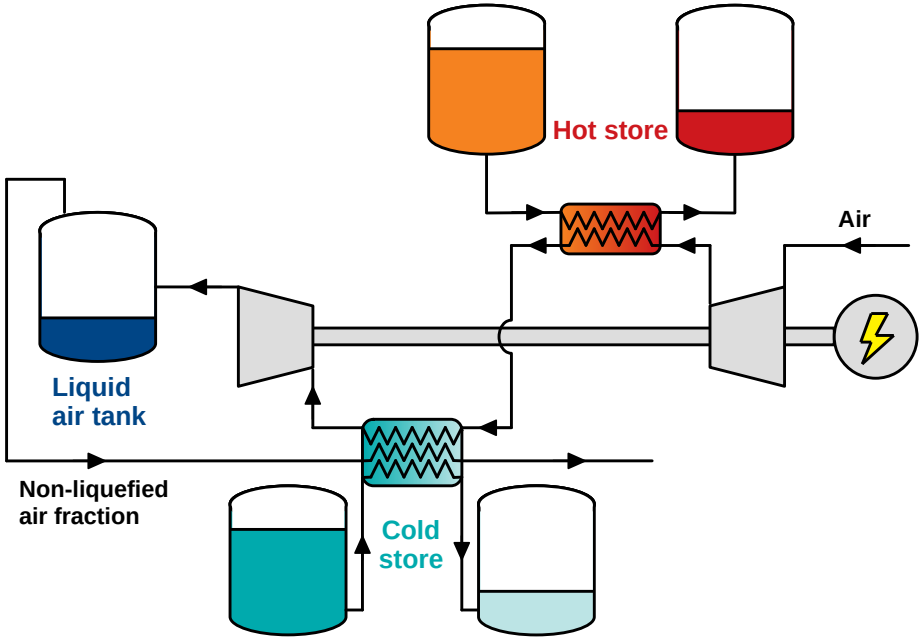
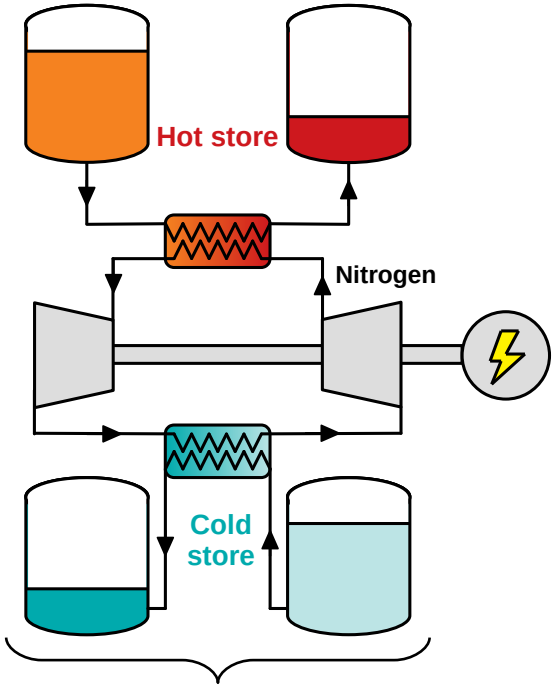


Material	Energy density (kWh_e/m^3)
Liquid air	170
Molten salt	80

Brayton–Liquid air

Brayton cycle



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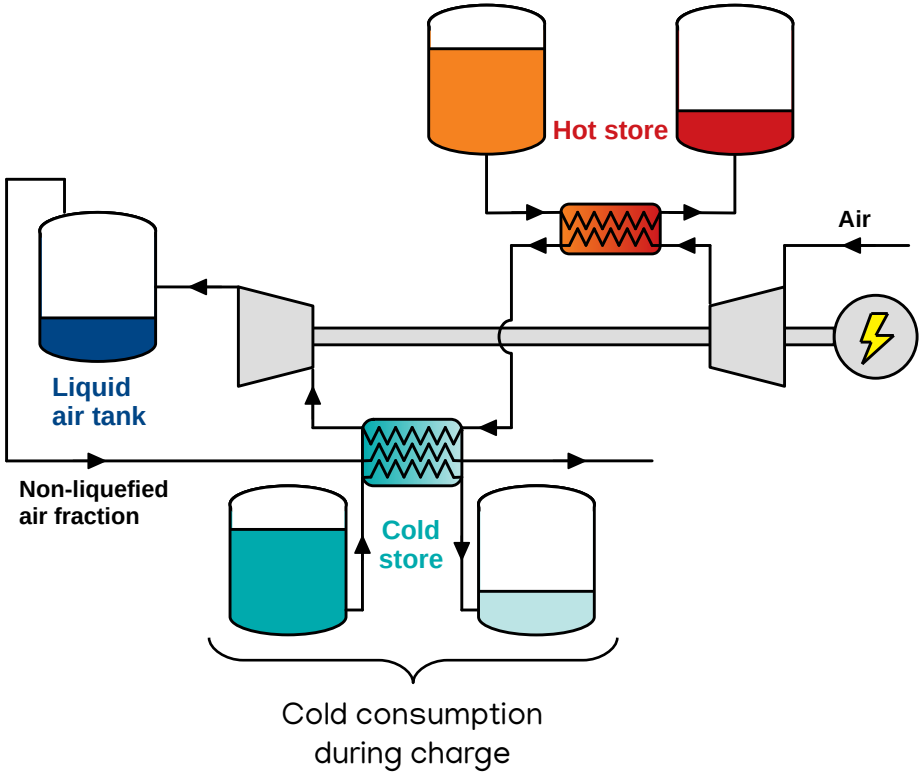
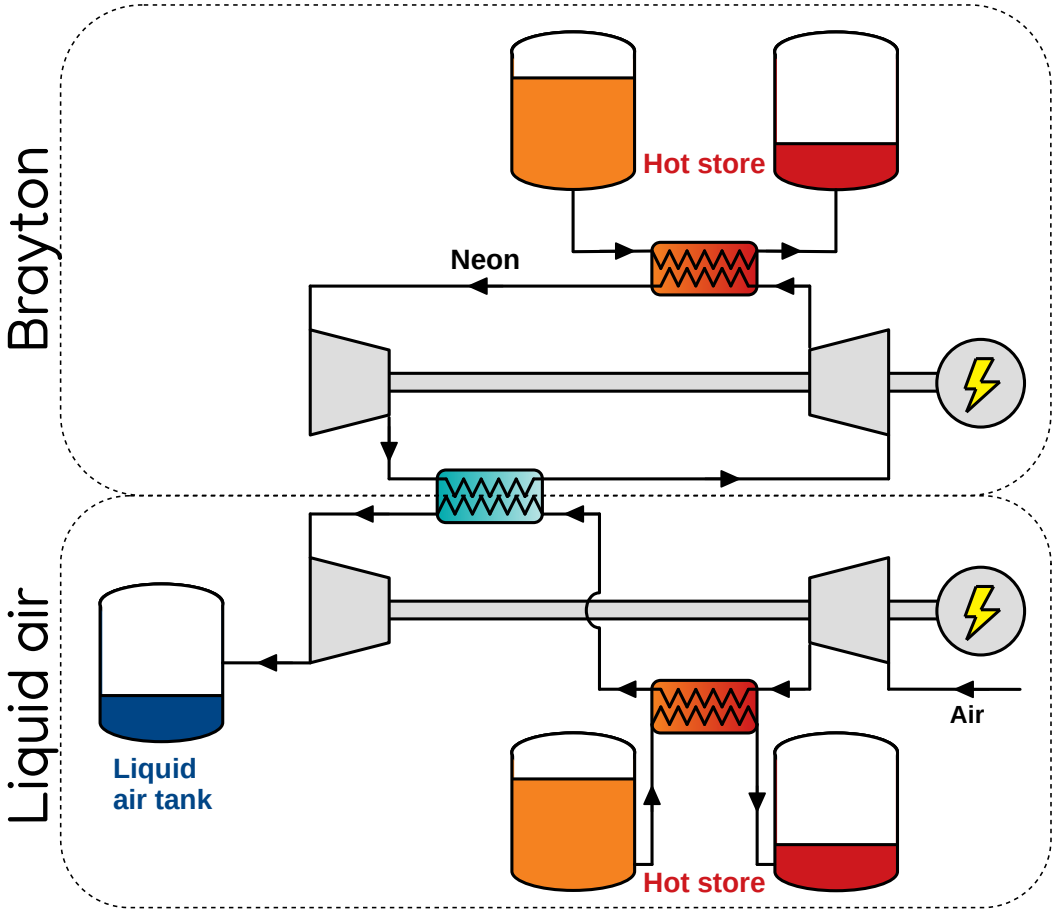
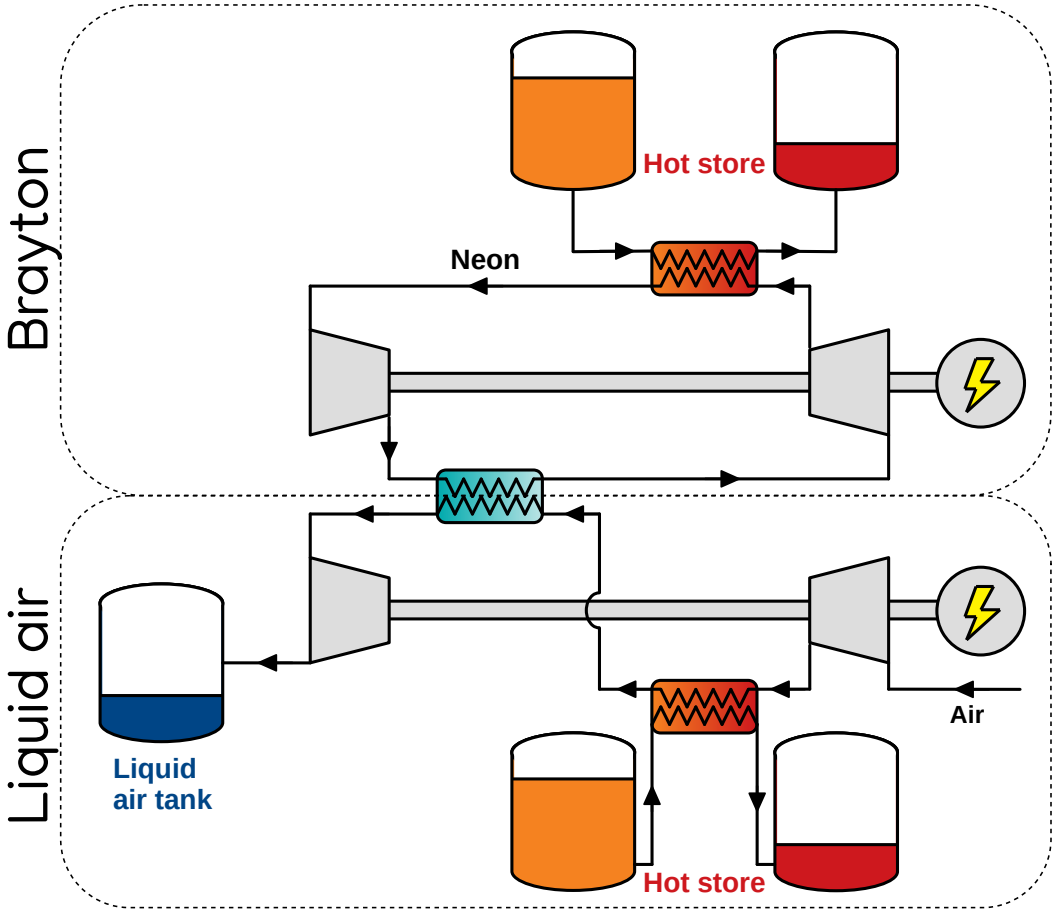


Brayton–Liquid air



- Heat exchanger substitutes two cold reservoirs
- Complete air liquefaction

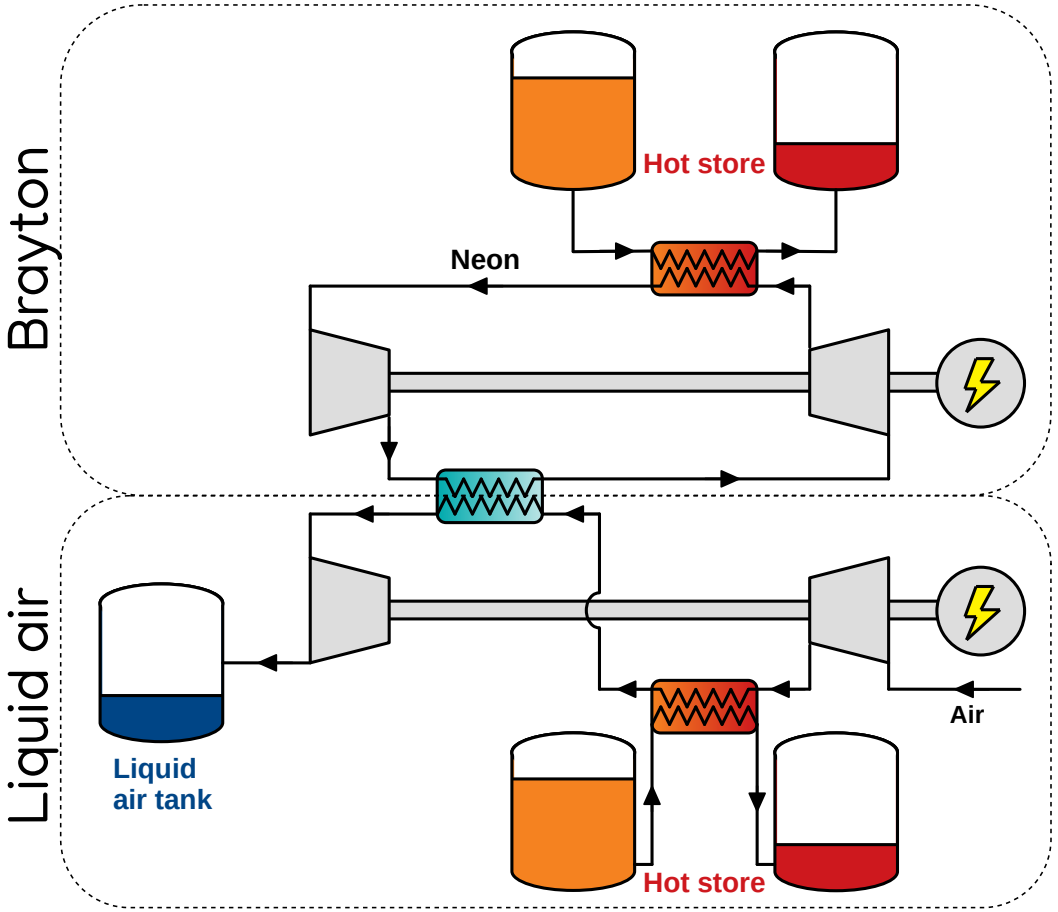
Brayton–Liquid air

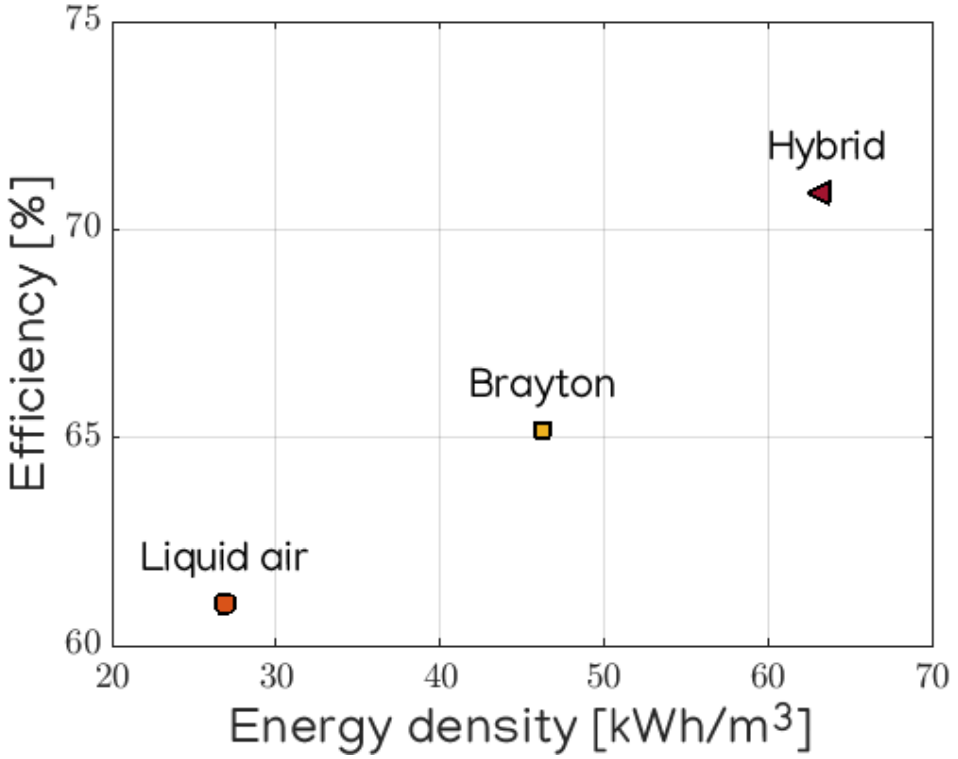


- Heat exchanger substitutes two cold reservoirs
- Complete air liquefaction

- Neon required
- Pinch point problem
  - → Increase air pressure (+150 bar)
  - → Use multi–stream heat exchanger

Brayton–Liquid air





Concluding remarks

- Hybrid Carnot Batteries can provide high performance or flexibility
- Brayton–Rankine
  - Energy storage + power generation
  - 60% round-trip efficiency
- Brayton–Liquid air
  - No cold reservoirs
  - 70% round-trip efficiency

Further reading...

[1] Vinnemeier et al. (2016). *Integration of heat pumps into thermal plants for creation of large-scale electricity storage capacities*. https://doi.org/10.1016/j.apenergy.2016.10.045

[2] Farres-Antunez et al. (2018). *Thermodynamic analysis and optimisation of a combined liquid air and pumped thermal energy storage cycle*. https://doi.org/10.1016/j.est.2018.04.016

[3] Farres-Antunez et al. (2019). *A pumped thermal energy storage cycle with capacity for concentrated solar power integration.* https://doi.org/10.1109/OSES.2019.8867222

[4] Steinmann et al. (2020). *Thermodynamic Analysis of High-Temperature Carnot Battery Concepts*. https://doi.org/10.1002/ente.201900895

[5] Olympios et al. (2020). *Progress and prospects of thermo-mechanical energy storage – A critical review* (submitted 2020). Progress in Energy.